Market Assessment of Forward-Looking Turbulence Sensing Systems

Research Sponsor:

NASA Weather Accident Prevention Project (WxAP)

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Overview

- Technologies and Study Objectives
- Study Approach
- Results:
  - Business Model: Injury rates, cost of injuries, indirect costs
  - Market penetration rate estimates
  - Product success characteristics

Objectives

- Identify cost and benefit data related to next generation of forward sensing turbulence technologies:
  - Enhanced X band, LIDAR, combined product
- Integrate into a business case that will evaluate feasibility of market success for the commercial transport fleet.

Technology Focus

- Examine three possible forward sensing turbulence system(s) that may achieve market success over the next 5-10 years:
  - 1) Next generation enhanced X band turbulence radar systems for convective turbulence.
  - 2) LIDAR based turbulence systems to sense clear air turbulence.
  - 3) A combined, hybrid system including both enhanced radar (X band) and LIDAR to sense both convective and clear air turbulence.

Study Approach

- Telephone interviews and data gathering
  - Structure issues and questions
  - Literature search
  - Information from a variety of sources
- Survey developed and analyzed
  - Corroboration of verbal data and other sources
  - Issue: small sample size

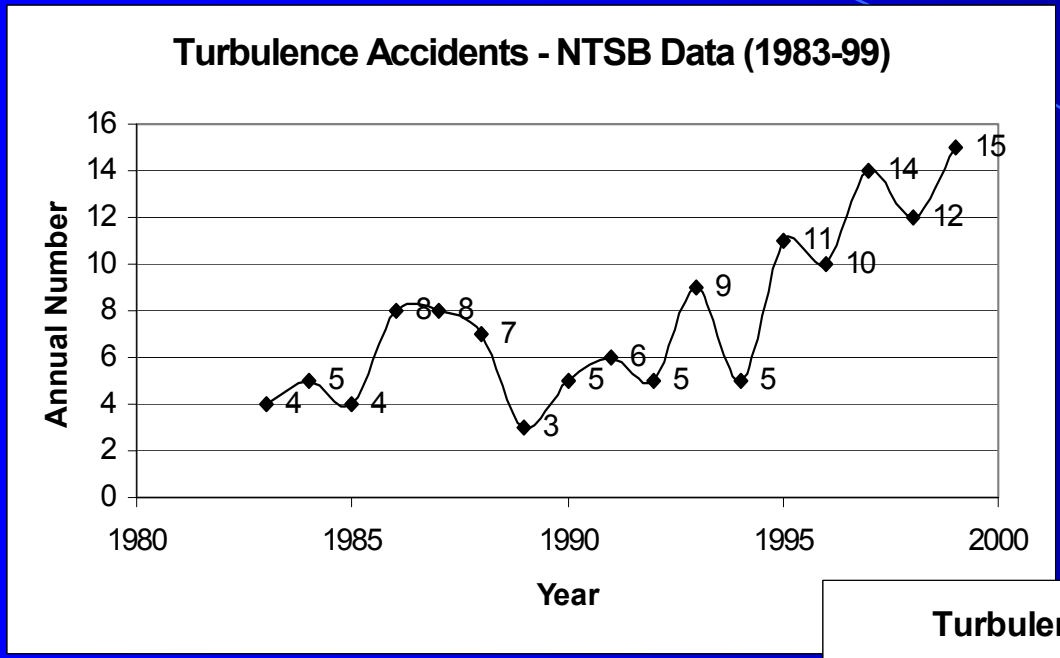
Business Case Equation

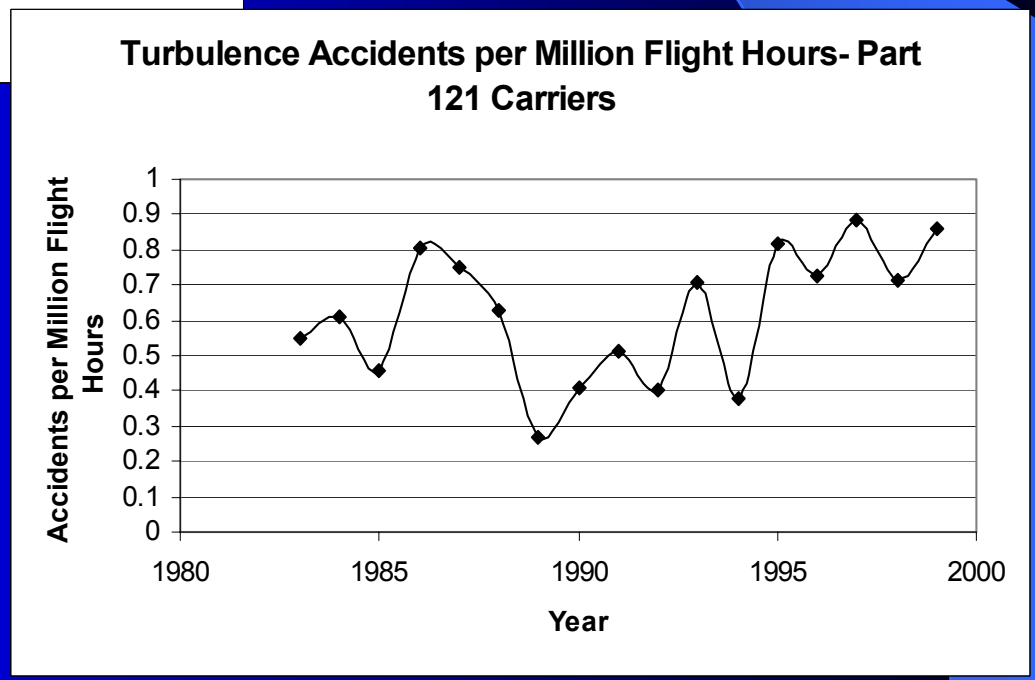
- Base Business Case defined by:
  - Net $ benefit of Turbulence System =
    - Investment – operating costs + savings from reduced turbulence accidents and incidents + savings from flight operations improvements (damage, diversions and flight time) + intangible benefits
  - Intangible benefits may be valued indirectly: the value to make case positive.

Accident / Incident Rates

- A variety of benchmarks:
  - AWS&T article: Part 121 carriers experienced an average of 130 events per year in a three - year period from 1994-96.
  - Study participant: 750 turbulence related events per year for Part 121 carriers.
  - FAA report: from 1981-1997, 342 reports of turbulence affecting major air carriers for an annual average of 27 events

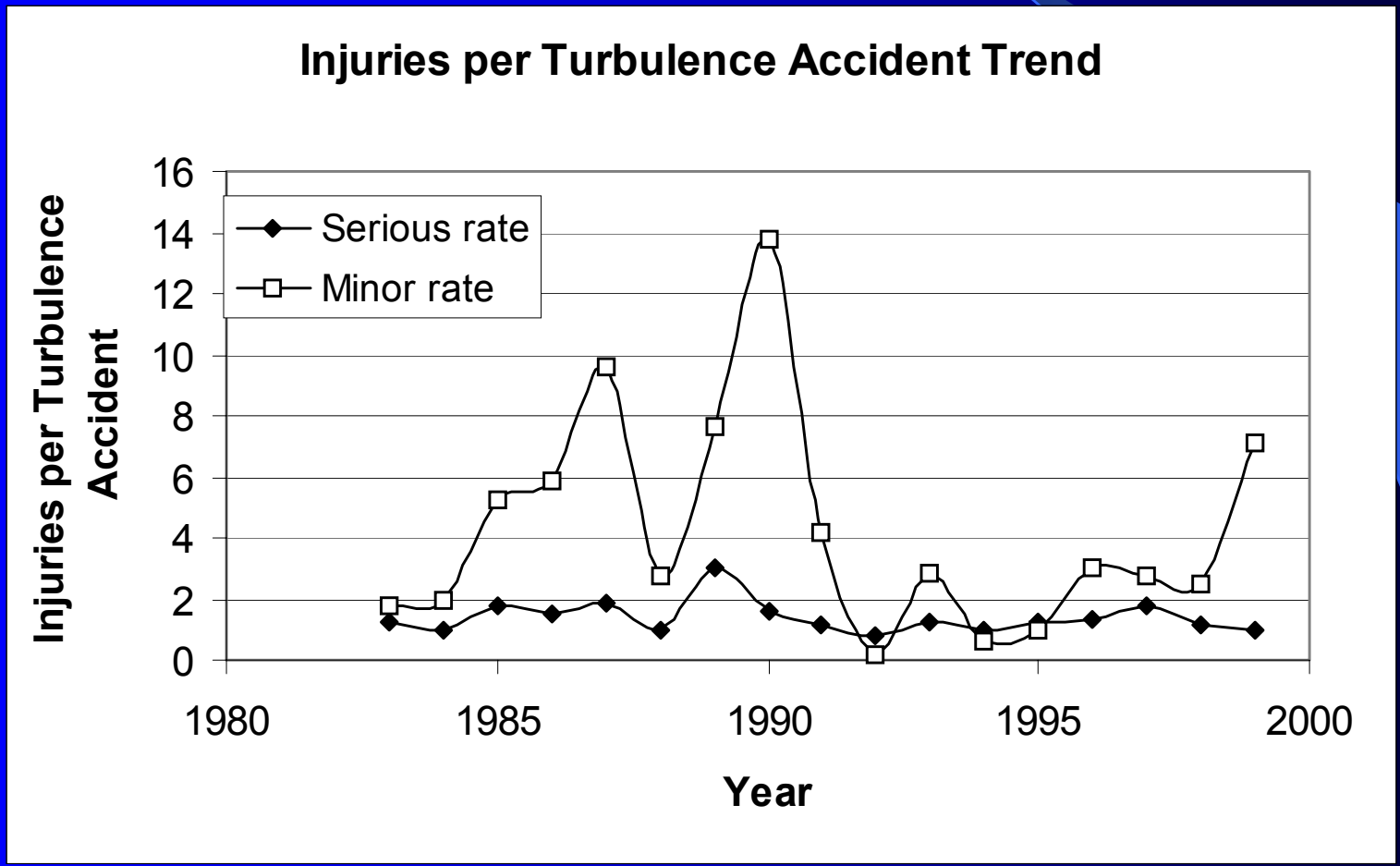
NTSB Accident Reports





Injury Rates

- Per NTSB data, injury rates per accident:



Data from Crew Reports

- Crew report data analyzed to develop an estimated annual average, for Part 121 fleet:

	Clear Air	Wake	Convective	Total	1999 NTSB Accidents
Turbulence events	136.6	123.8	529.4	789.8	NA
Injury events	106.7	89.7	371.4	567.8	15
Minor FA injuries	123.8	132.3	431.2	687.4	20
Serious FA injuries	17.1	0.0	21.3	38.4	10
Minor PA injuries	17.1	12.8	89.7	119.5	87
Serious PA injuries	0.0	8.5	8.5	17.1	5

Airline executive: 200 passenger and 235 workers compensation claims for turbulence related injuries in 1997.

Survey Participant Estimates

- Survey participants estimate higher annual incidents:

Annual turbulence incidents for Part 121 Carriers		
Lower 90% interval	Most Likely	Upper 90% Interval
151	210	269

FAA Injury Costs

- "Willingness to Pay" approach:

Classification	Willingness to Pay	Emergency / Medical	Legal / court	Total Value
Death	$2.7M	Not a significant addition to WTP value		$2.7M
Minor injury	$34,000	$2,000	$2,500	$38,500
Serious Injury	$482,000	$27,600	$12,200	$521,800

Issue: Unclear how these costs relate to business case in industrial setting.

Other Benchmarks for Injury Costs

- Lindsey (2000): average FA injury cost is $10k-15k and average passenger injury between $50,000 - $60,000 (combined serious and minor).
- Search (2000): direct payment cost of $600k for serious passenger injuries and $100k for minor injuries. Total annual Part 121 cost of FA injuries is $11M.

Survey Results

- Survey response estimates:

	Survey: 90% Confidence Interval for mean cost of injury		
Injury Category	**Lower**	**Expected**	**Upper**
Serious Flight Attendant	64748	164286	263823
Minor Flight Attendant	9292	25000	40708
Serious Passenger	76587	170000	263413
Minor Passenger	3256	33333	63411

Total Injury Cost Estimate

- Using data from this study:

Injury Category	Annual Injuries (Table 4)	Expected Cost $	Total Cost $
Minor Flight Attendant	687.4	25,000	17,184,125
Serious Flight Attendant	38.4	164,286	6,312,536
Minor Passenger	119.5	33,333	3,984,725
Serious Passenger	17.1	170,000	2,903,157
	Total Annual Part 121 Industry Injury Cost		30,384,542

Industry Cost Benchmarks

- Turbulence costs are $30M- $60M:

	Survey	Lindsey	Search	FAA
	Table 9	Average flight attendant injury: $12,500	Flight attendant injury cost not estimated	Serious injury: $521,800
	Table 9	Average passenger injury: $55,000	Serious passenger injury: $600,000 Minor passenger injury: $100,000	Minor injury: $38,500
Minor Flight Attendant	17,184,125	9,072,364	$11,000,000 estimated as total flight attendant cost	Total serious injury cost: $28,960,694
Serious Flight Attendant	6,312,536			
Minor Passenger	3,984,725	7,514,052	11,954,174	Total minor injury cost: $31,065,910
Serious Passenger	2,903,157		10,246,435	
Total Part 121 Cost Estimate	**30,384,542**	**16,586,416**	**33,200,609**	**60,026,604**

Convective or Clear Air?

- What proportion of the costs are related to CAT? (LIDAR vs X Band)
  - For analysis: 2/3 incidents are convective

	Convective	Clear Air	Wake / Other
Table 4- Crew Reports	67%	17%	16%
Clark (1997)	50%	33%	17%
Lindsey (2000)	50%	34%	16%

Issue: Is CAT over reported?

Non – Recurring Investment

- From the survey data:

	OEM Purchase Cost			Retrofit Cost		
	-90%	Expected	+90%	-90%	Expected	+90%
X Band	25728	44643	63558	29865	43750	57635
LIDAR	48193	72500	96807	66182	87500	108818
Combined	59147	82500	105853	85823	97500	109177

Confidence intervals for mean cost shown

Differentiated based on original purchase on new aircraft and cost to retrofit existing fleet.

Operational Savings

- Operational Savings:
  - Fuel Savings: Search estimated $595 per aircraft per year
  - Diversions: Three found in the crew reports. Lindsey indicates that most continue.
  - Aircraft damage: Primarily cart and cabin related.
- Conclusion: Operational savings appear to be marginal decision factors

Business Case Injury Cost

- Consider investment for Part 121 carrier with 600 aircraft (per aircraft basis):
  - 80% success

	Total	Clear Air	Wake	Convective
Fatality events @ 0.2 /yr for industry	$108,000	$20,301	$17,053	$70,647
Minor Flight Attendant	$3,719,304	$669,937	$716,139	$2,333,228
Serious Flight Attendant	$1,366,277	$607,234	$0	$759,043
Minor Passenger	$862,439	$123,206	$92,404	$646,829
Serious Passenger	$628,354	$0	$314,177	$314,177
Total	$6,684,374	$1,420,677	$1,139,773	$4,123,924
Annual cost per aircraft	$11,141	$2,368	$1,900	$6,873

X Band Case -Possibly Favorable

- Using 12% rate, five years, retrofit option and 80% reduction:
  - Intangibles: diversion, damage, others

Percent injury cost reduction	80%	
Business decision based on single aircraft model	X Band Base Case	Value to Reverse Decision
Non Recurring Investment	$43,750	$21,966
Annual injury savings	$5,499	$11,542
Annual operating savings	$595	$6,638
Annual intangible benefits	NA	$6,043
Increased annual maintenance	0	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$21,784	

LIDAR Business Case- Unfavorable

- Possible market potential appears small:

Percent injury cost reduction	80%	
Business decision based on single aircraft model	LIDAR Base Case	Value to Reverse Decision
Non Recurring Investment	$87,500	$7,600
Annual injury savings	$1,894	$28,053
Annual operating savings	$595	$26,754
Annual intangible benefits	NA	$26,159
Increased annual maintenance	$4,375	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$94,298	

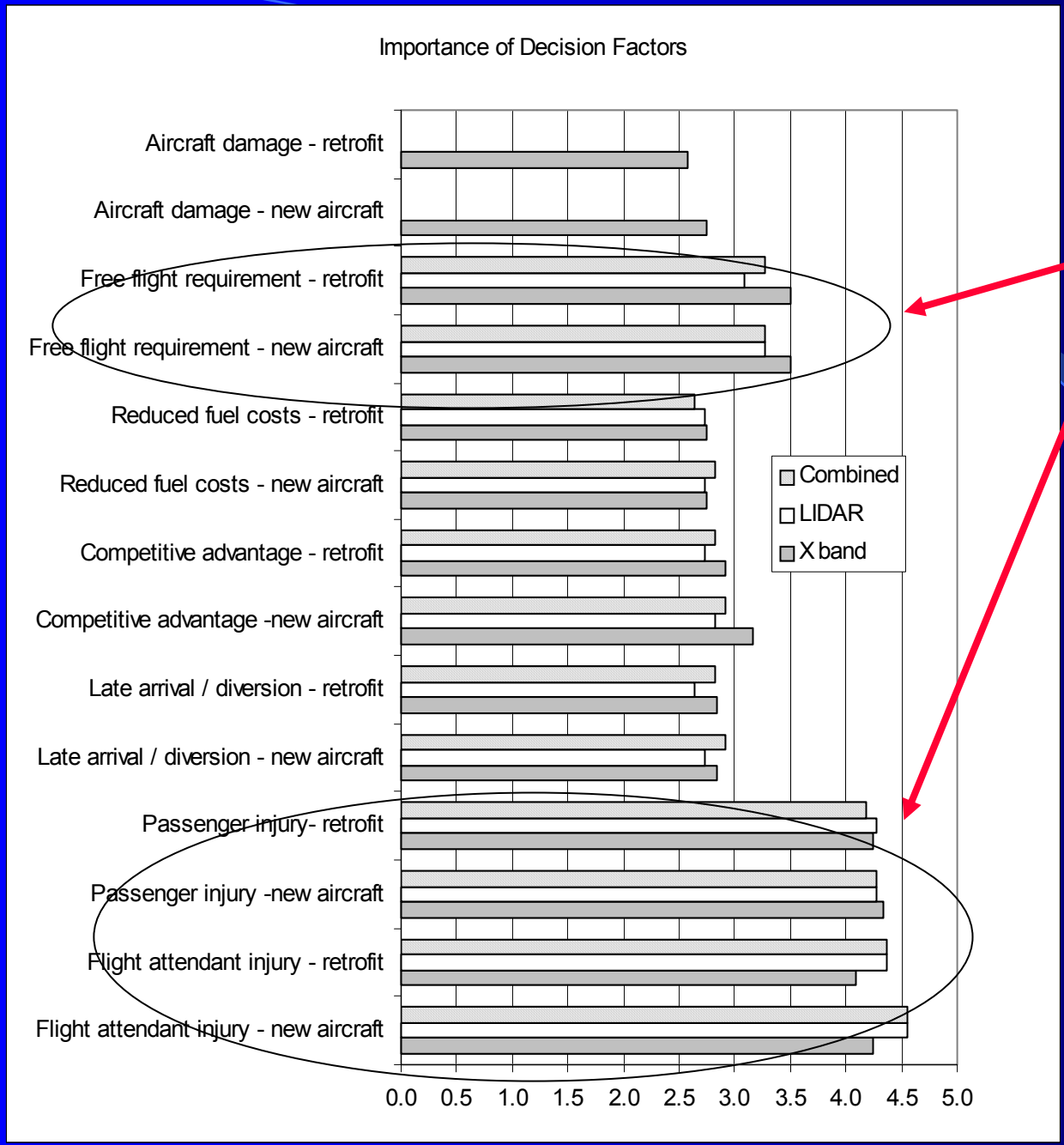
Combined Product Case-Unfavorable

- Incremental expenditure over X band appears unjustified:

Percent injury cost reduction	80%	
Business decision based on single aircraft model	Combined Base Case	Value to Reverse Decision
Non Recurring Investment	$97,500	$11,221
Annual injury savings	$7,393	$31,327
Annual operating savings	$595	$24,529
Annual intangible benefits	NA	$23,934
Increased annual maintenance	$4,875	NA
Project life	5	NA
Rate of return	12%	NA
Net present value	-$86,279	

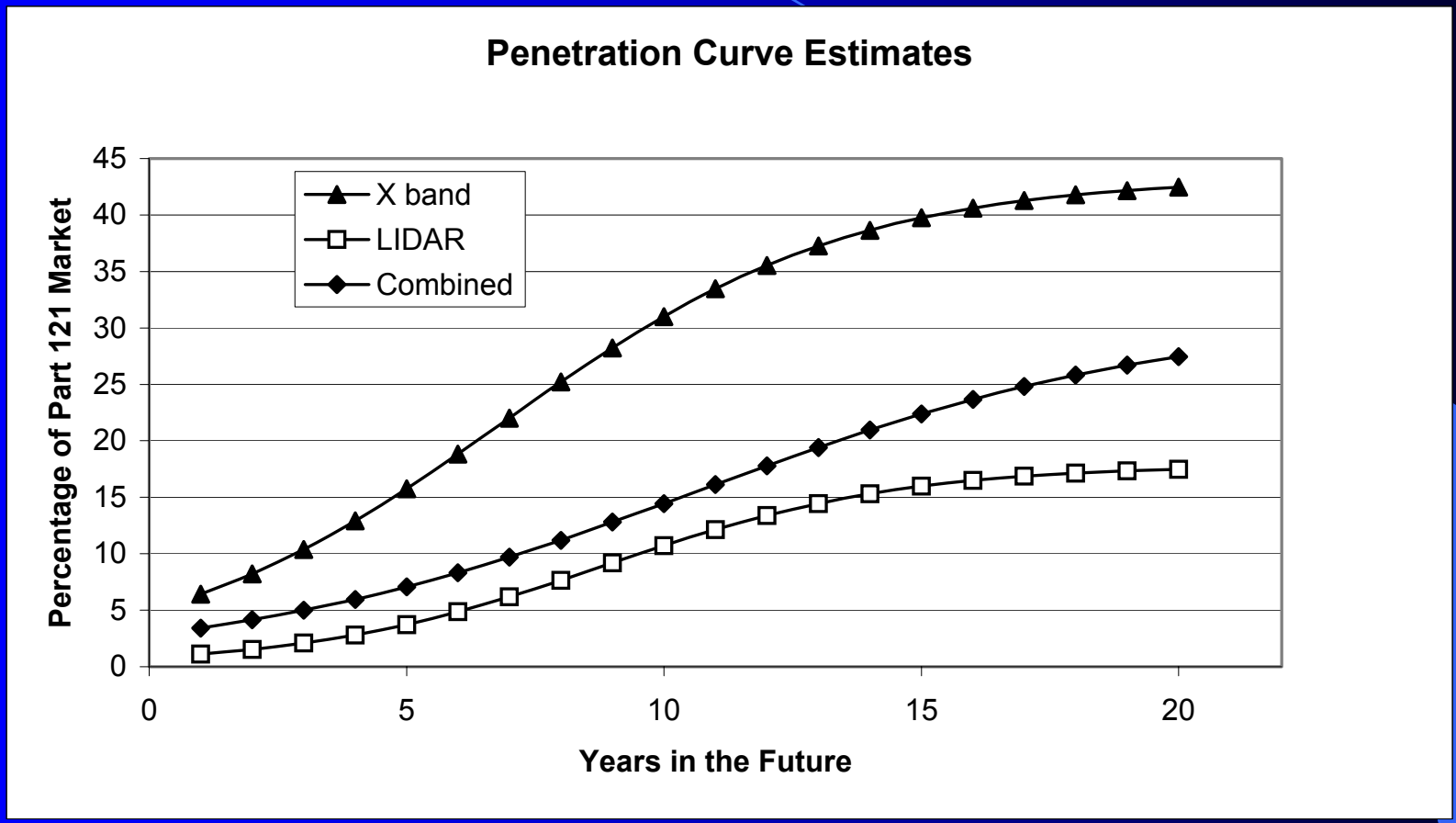
Business Case Issues

- Influence of other factors:
  - Competition to own cockpits
  - Market leadership: Integrated suite of weather products
  - Demonstrated commitment to Safety
  - Competitive pressures if lead adopter purchases
  - Long flights and out of seat entertainment
  - Issue of free flight



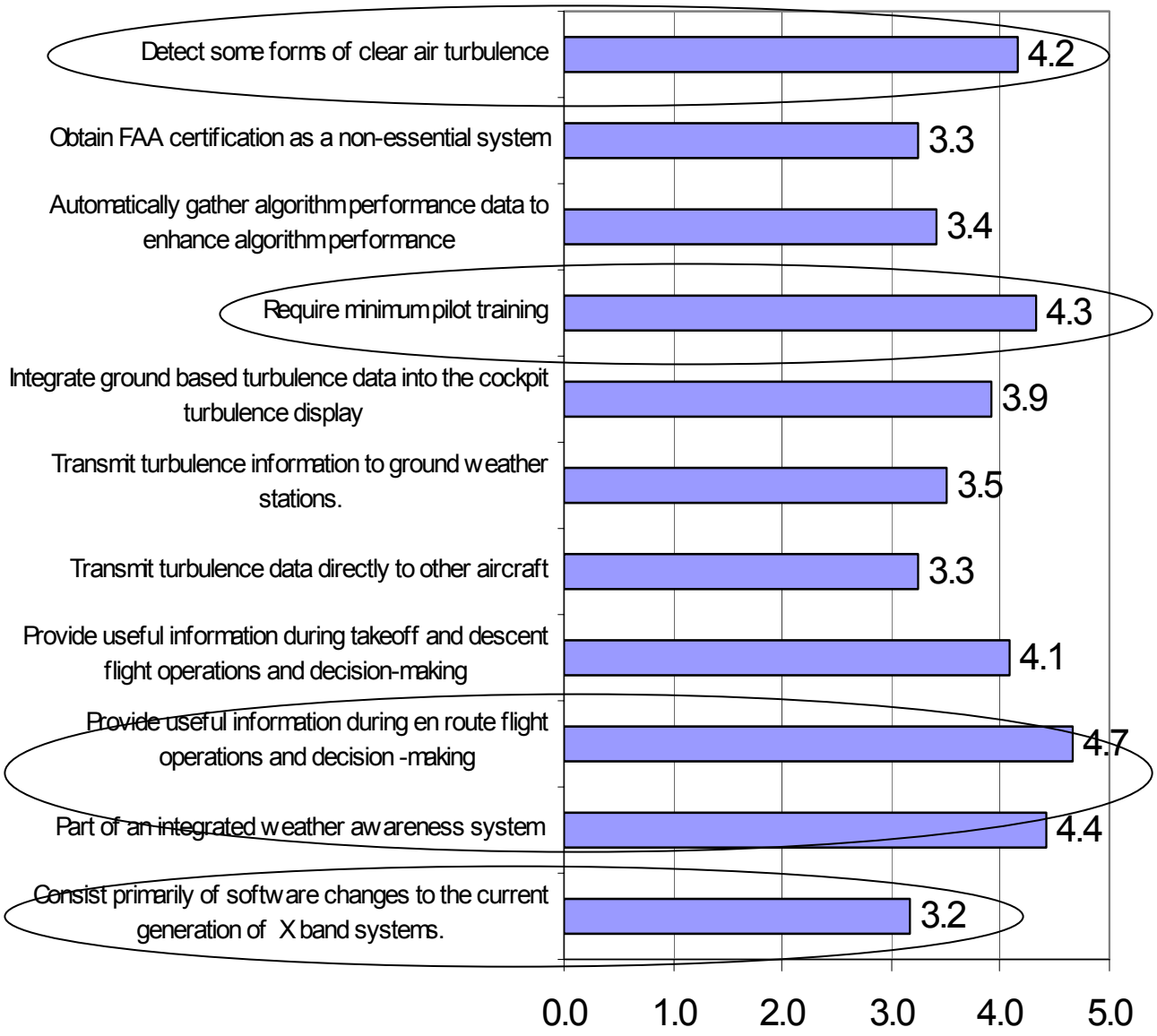
Survey importance of decision factors in business case decision

Market Penetration Estimates

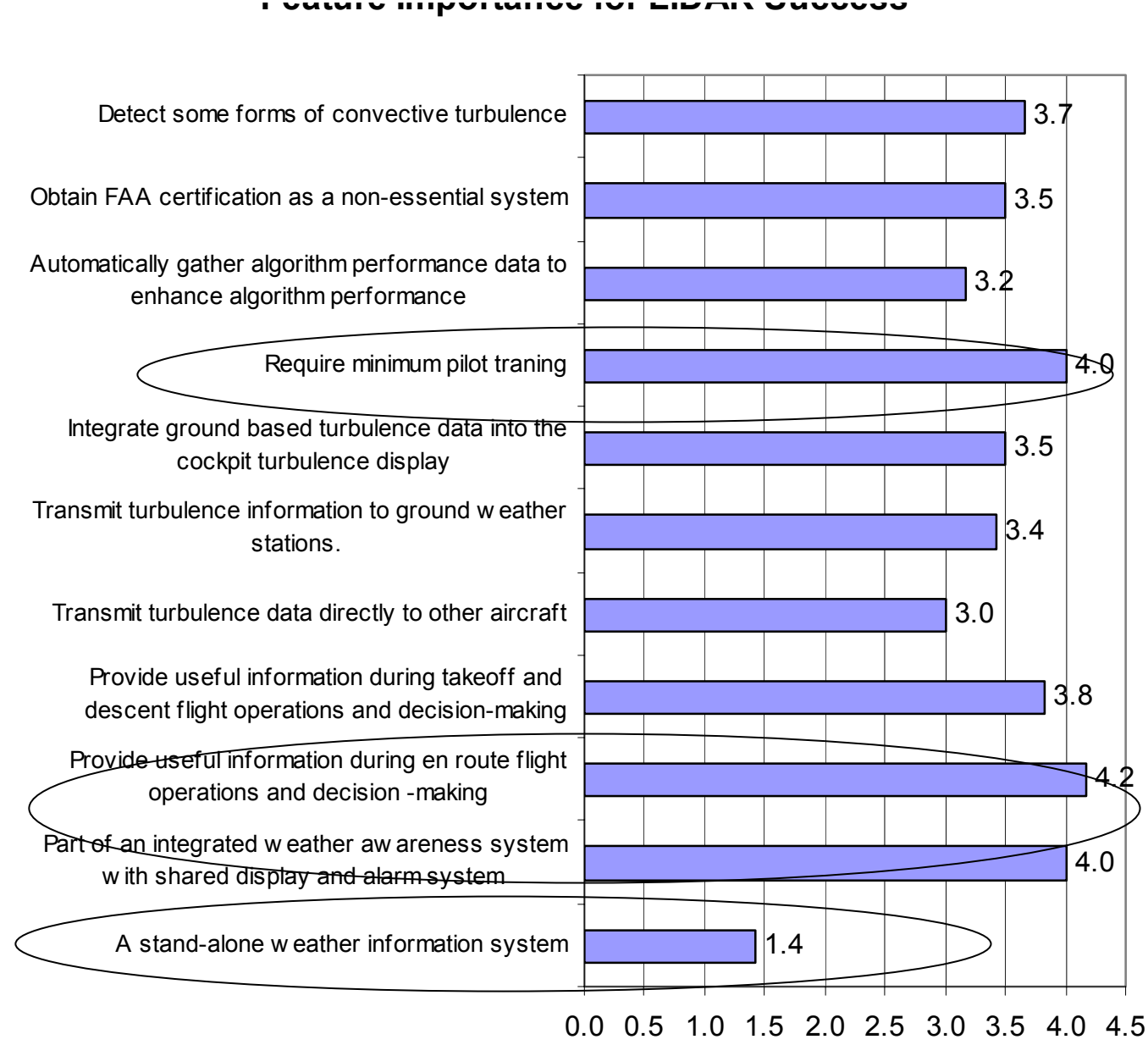


Penetration rates consistent with weak business case

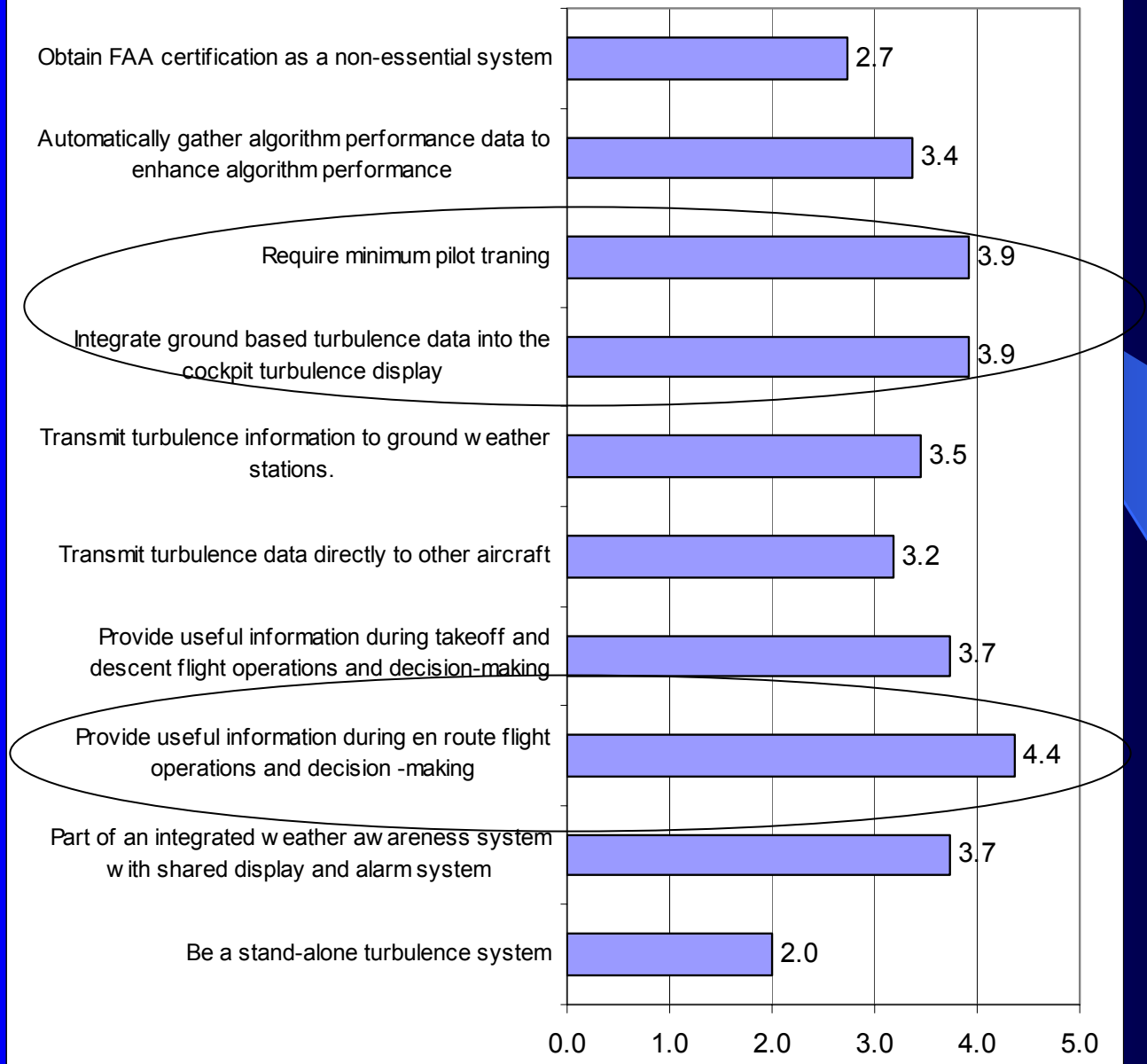
X Band Product Characteristics



LIDAR Product Characteristics



Combined Product Characteristics



Summary of Success Characteristics

- Part of an integrated weather awareness system
- Minimum pilot training (human factors)
- Focus on en route data but descent and take off also important
- Integrate ground based turbulence data.

Turbulence Warning

- Estimated minimum warning for market success:

	Expected Warning in Minutes		
	Severe Turbulence	Moderate Turbulence	Light Turbulence
X band	3.06	2.16	1.13
LIDAR	2.68	1.93	1.06
Combined	3.53	2.30	1.28

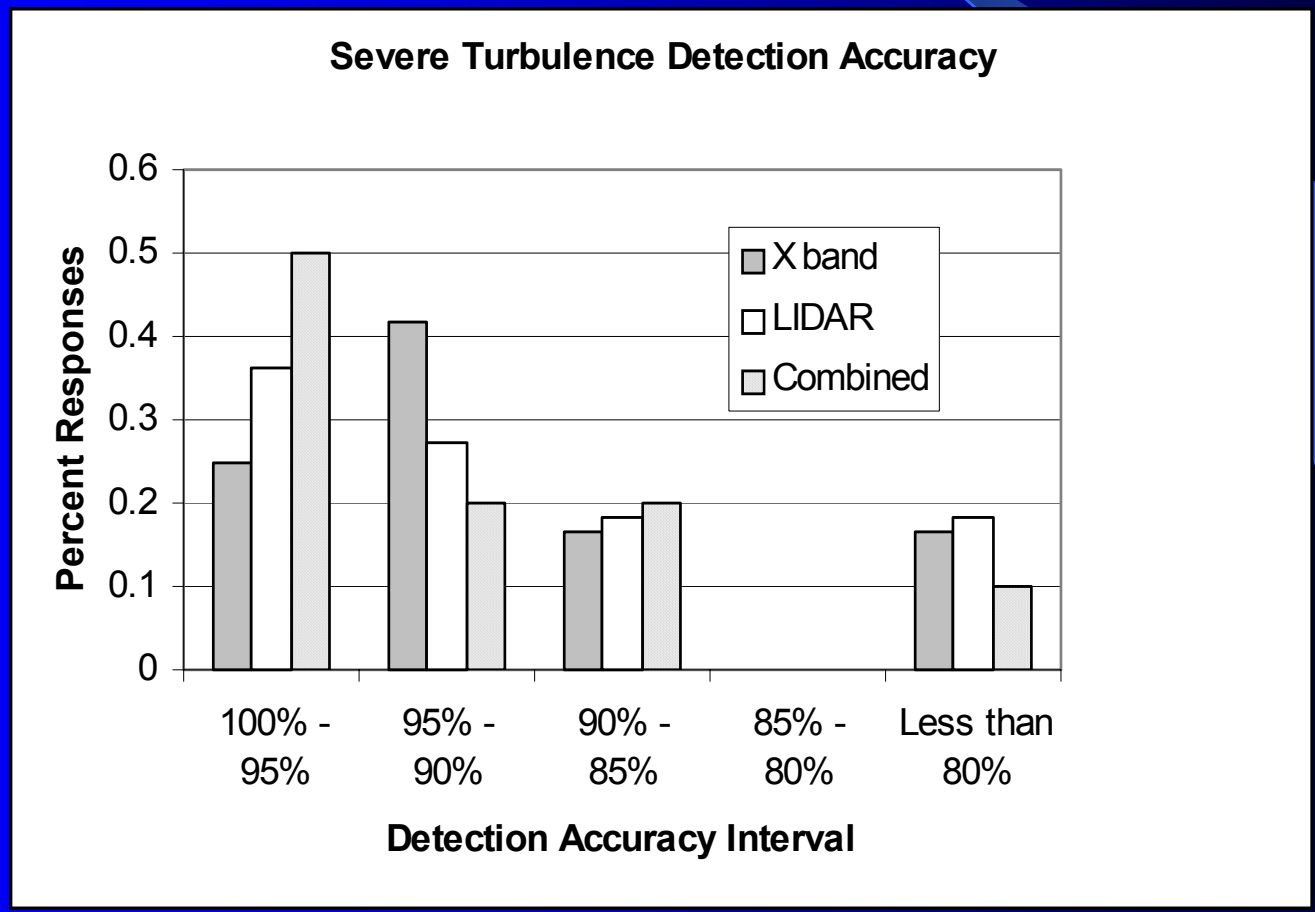
Detection Accuracy

- Accuracy threshold for market success:

	Expected Accuracy		
	Severe Turbulence	Moderate Turbulence	Light Turbulence
X band	90%	88%	83%
LIDAR	91%	88%	84%
Combined	93%	90%	85%

Example of Distribution

- The averages represent a range of accuracy estimates. For example:



Summary

- Market potential primarily based on injury cost reduction
- X band has the greatest market potential
  - Initial costs must be kept low
  - System integration, accuracy, and ability to detect some clear air turbulence are critical.
- LIDAR and a Combined product have a very weak business case
  - Market penetration potential: new aircraft for long flights.